Fishery Data Series No. 10-41

Abundance and Composition of Northern Pike in Volkmar Lake, 2009

by

Klaus Wuttig

June 2010

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm
Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd
Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s
Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General	
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	\$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)	
fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL
Mathematics, statistics	
all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA SERIES NO. 10-41

ABUNDANCE AND COMPOSITION OF NORTHERN PIKE IN VOLKMAR LAKE, 2009

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ABSTRACT

The primary purpose of the study was to collect abundance information for northern pike Esox lucius ≥450 mm FL in Volkmar Lake to evaluate potential regulatory changes during the 2010 Board of Fish meeting. A minimum population size of 2,000 northern pike ≥450 mm FL was the threshold above which regulatory changes to increase harvest would be supported by the department. Abundance and length composition of northern pike ≥300 and ≥450 mm FL during 2009 were estimated using a two-event mark-recapture experiment. A combination of beach seines and hook-and-line gear was used to sample fish during the first (May 20–24) and second (May 28–31) events. The estimated abundance for northern pike ≥300 and ≥450 mm FL was 4,832 (95% C.I. = 4,124-5,539) and 4,017 (95% C.I. = 3,417-4,614), respectively. Length distribution of sampled fish was unimodal, 77% of the fish were between 500 and 700 mm FL, median length was 600 mm, and lengths ranged from 255 to 1030 mm. The estimated population size far exceeded the threshold and after considering this information the Board of Fisheries increased the bag limit from a one fish to two fish.

Key words: northern pike, *Esox lucius*, Volkmar Lake, abundance, mark-recapture, composition.

INTRODUCTION

Volkmar Lake is a semi-remote 373-ha lake located approximately 25 km northeast of Delta Junction (Figures 1 and 2). It is at an elevation of 326 m, has a maximum depth of 12.8 m, and a shoreline circumference of 8.2 km. The lake has two small inlets and an ill-defined outlet that drains westerly through wetlands towards the Goodpaster River. Nearshore waters are shallow, with beds of aquatic vegetation providing spawning and rearing substrate for northern pike *Esox lucius*. Volkmar Lake is typically ice-free from mid-May to early October and spawning of northern pike generally coincides with the beginning of the ice-free period and continues for up to two weeks into late May. Other fish species present in the lake include humpback whitefish *Coregonus pidschian*, least cisco *C. sardinella*, and slimy sculpin *Cottus cognatus*.

Volkmar Lake supports the second largest northern pike *Esox lucius* lake fishery in the Upper Tanana Management Area. The popularity of Volkmar Lake is attributed to: 1) its picturesque setting; 2) close proximity to Delta Junction and Fort Greely; 3) private lands and cabins around its shoreline; 4) numerous recreational cabins and private lands along the neighboring Goodpaster River; and, 5) its relatively easy winter access. During summer access is restricted to float-equipped aircraft, and therefore fishing occurs almost exclusively during the winter and spring when most anglers snowmachine from Quartz Lake or by crossing the Tanana River from Sawmill Creek Road, which extends out of Delta Junction.

Almost all of the sport fishing effort in Volkmar Lake is directed at northern pike because of the absence of other sport fishes. After a period of relatively stable catch, effort and harvests during the 1980s, the popularity of Volkmar Lake peaked during the early to mid-1990s (Figure 3), after which effort, catch and harvest dropped off considerably. The drop in catch, effort and harvest is attributed to an apparent sharp decline in the population size and a concurrent change in the fishing regulation. The decision to reduce the bag limit from five fish to one fish was based on an increase in of harvest in 1995 (1,084 fish) and an apparent decline in the population based on several angler reports in 1996 and 1997 from long-time users of the lake when no current stock status information was available. In 2000, a stock assessment was conducted and the estimated abundance of northern pike ≥450 mm FL was 615 (SE = 161), which confirmed suspicions of a reduced population size (Scanlon 2001).

In 2005, another stock assessment was conducted to address potential regulatory proposals for the 2007 Board of Fisheries meeting, whereby, the public sought to raise the bag limit for northern pike. At this time, catch reports from anglers indicated that the population may have rebounded from the low levels experienced in 2000. An estimated abundance of 2,000 fish ≥450 mm FL was selected by the area manager as the minimum threshold at which the department would support regulatory changes to increase harvest of northern pike in Volkmar Lake. Hansen and Pearse (1995) predicted a theoretical maximum sustained yield of 300 fish with a spawning population of 2,000 spawners. In 2005, the estimated abundance was 1,814 (SE = 864) fish ≥450 mm FL indicating an increase in population size, but the increase was insufficient to allow more liberal fishing regulations.

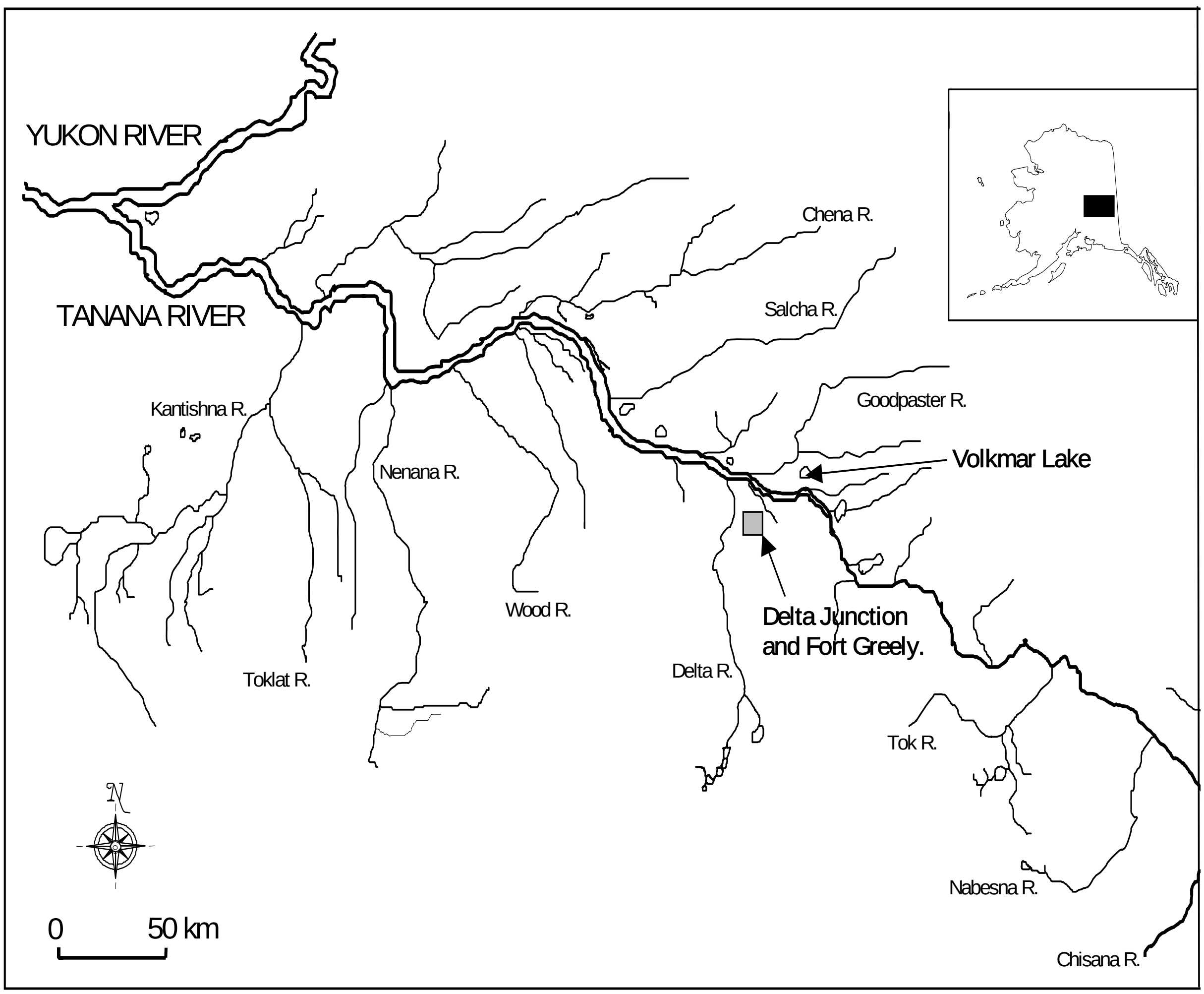

Figure 1.–Location of Volkmar Lake.

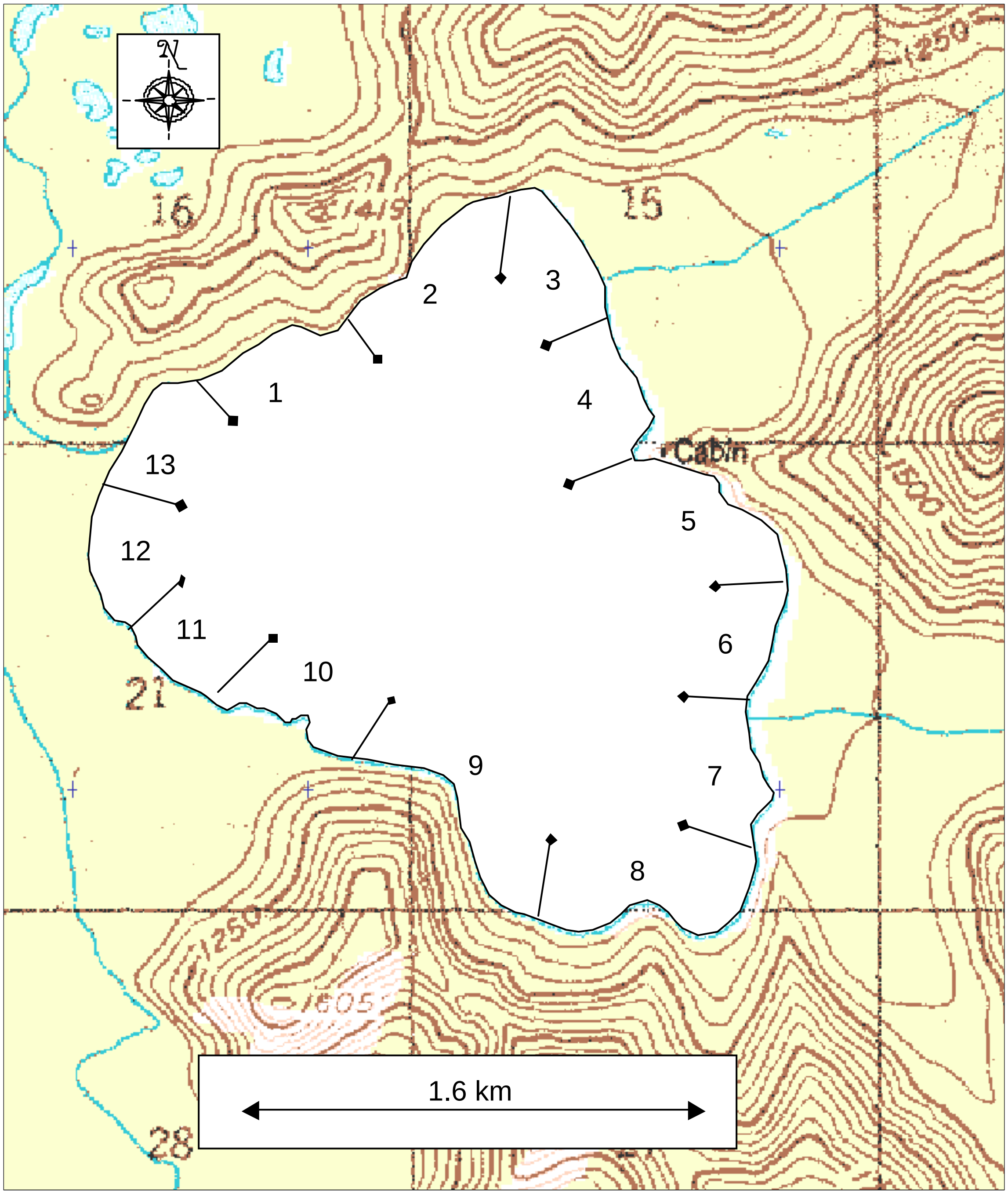

Figure 2.–Volkmar Lake with demarcations of sample sections.

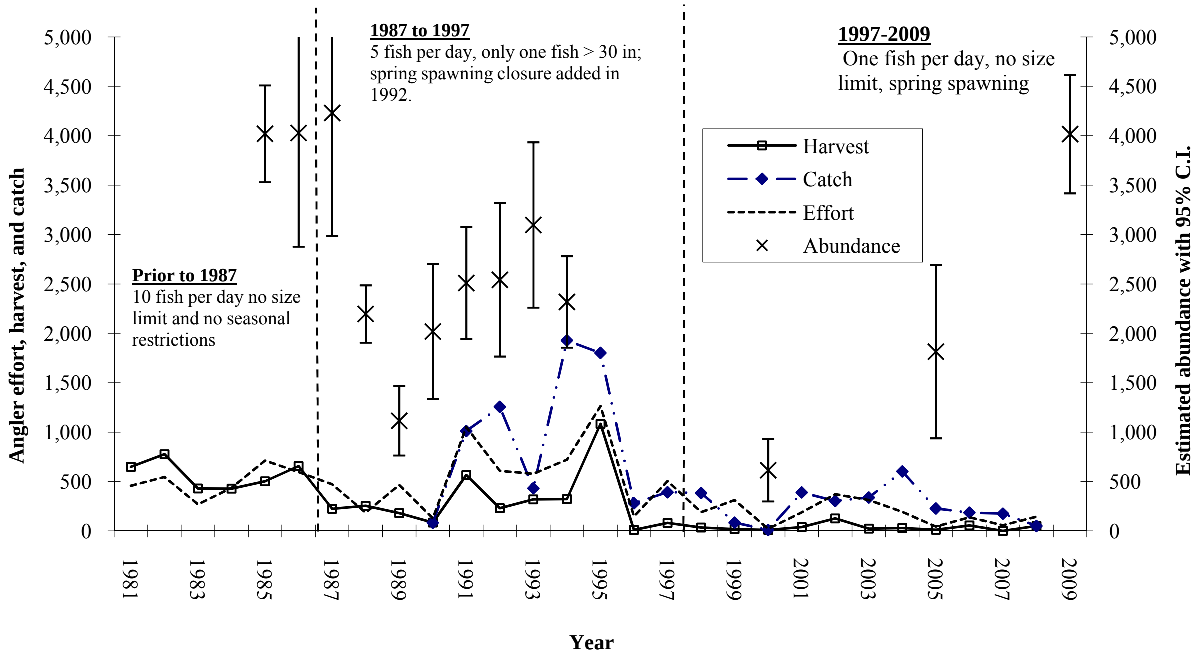

Figure 3.–Historic estimates of angler effort, harvest, and catch, and estimates of abundances for mature-sized pike (≥450 mm FL) for Volkmar Lake. Vertical dashed lines demarcate relevant regulatory changes. Estimates of effort, harvest and catch were presented in Parker (2009) and estimates of abundance prior to 2009 were presented in Hansen and Pearse (1995), Scanlon (2001), and Wuttig and Reed (*in prep*).

In 2010, the area manager submitted a proposal to the Board of Fisheries to raise the bag limit from one to two or three fish to provide for additional harvest opportunity. Recent effort, catch and harvest trends indicated that a small increase in bag limit would be sustainable provided the population size exceeds 2,000 northern pike (≥450 mm FL). This study was designed to determine whether the northern pike population in Volkmar Lake had reached the minimum threshold to allow for more liberal regulations. It was also determined that the annual harvests should not exceed 300 fish or 15% exploitation of the estimated abundance.

OBJECTIVES

The research objectives for Volkmar Lake in 2009 were to:

1) test the null hypothesis that the abundance of northern pike ≥450 mm in Volkmar Lake was ≤2,000 with 50% power of rejecting the null hypothesis if the true abundance was ≥2,518 using alpha = 0.05;
2) estimate the abundance of the northern pike population ≥450 mm FL in Volkmar Lake during 2009 such that the estimate was within 25 percentage points of the actual value 95% of the time; and,
3) estimate the length composition of the northern pike population ≥450 mm FL in Volkmar Lake such that the estimates of proportions were within 5 percentage points of the actual value 95% of the time.

Additional project tasks were to:

1) estimate the abundance of northern pike ≥300 mm FL; and,
2) estimate the length composition of the northern pike population ≥300 mm FL in Volkmar Lake.

Objective 1 related directly to the sustainable population size and the desired level of certainty needed to evaluate proposals to liberalize fishing regulations. Objective 2 was included because this level of precision was desired regardless of population size. Task 1 related to the minimum size limit attained in some previous studies and, when combined with Task 2, provided insight on the magnitude of recruitment.

METHODS

EXPERIMENTAL AND SAMPLING DESIGNS

Petersen mark-recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

1. the population is closed (northern pike do not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all northern pike will have a similar probability of capture in the first event or in the second event, or marked and unmarked northern pike will mix completely between events;
3. marking of northern pike will not affect the probability of capture in the second event;
4. marked northern pike will be identifiable during the second event; and,
5. all marked northern pike will be reported when recovered in the second event.

The estimator used was a modification of the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \qquad (1)$$

where:

n_1 = the number of northern pike marked and released during the first event;

n_2 = the number of northern pike examined for marks during the second event; and,

m_2 = the number of marked northern pike recaptured during the second event.

The sampling design and data collected allowed the validity of the five assumptions to be ensured or tested. The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met (Appendices A1–A4).

The start date was based on the first day the lake could be accessed after ice-out. Ice-out was prolonged due to a lack of wind and a pan of ice was still on the lake the day prior to arrival. The first event occurred May 20–24 and the second May 28–31. To assist in the distribution of sampling effort, the study area was divided into 13 asymmetric sections (Figure 2). The distribution and length of the sampling sections were selected based on the historic distribution of catches and helped to distribute effort proportionate to fish densities.

During the first event, a beach seine (100 x 10 m with 25 mm square mesh and an attached bag) was primarily used (hook-and-line was secondary) using a five-person crew. One seine haul per section was conducted each day (Table 1). When seining or angling, lake sections were generally fished sequentially in a clockwise direction. To guard against any potential diel patterns in fish movement related to environmental factors (e.g., water temperature, time of day, or weather) that could have affected capture probabilities, sampling began each day in a different section (Table 2). Hook-and-line was opportunistically used to sample areas that could not be as effectively seined (such areas 5, 9, and 10 with steep shorelines). Angling was conducted after seining and the crew split into two teams and fished their assigned areas using an assortment of single-hook, artificial lures. Gillnetting was to be used but was quickly abandoned after just three 15-min sets because it was too stressful on the fish and hook-and-line sampling was just as effective.

During the second event, a six-person crew captured fish and effort was again systematically applied. Hook-and-line was the primary capture gear and beach seining was conducted until catches dropped off after the first couple of days (Table 1). Hook-and line effort was used in nearshore and offshore areas using three two-person teams fishing their assigned areas.

The study design ensured that the assumption of closure was not violated. Volkmar Lake is a closed system with the exception of a small outlet considered too small to serve as a migration corridor for non-juvenile fish. This study was of short duration, and therefore, growth recruitment and mortality were assumed to be insignificant. Sampling offshore areas with hook-and-line served to guard against isolated pockets of fish being unsampled in either event in the absence of mixing. The hiatus between events promoted mixing of marked and unmarked fish and allowed marked fish to recover from the effects of handling between events.

DATA COLLECTION

All fish were measured for length (mm FL), and carefully examined for marks. In the first event, all fish ≥250 mm FL were tagged with an individually numbered Floy™ FD-94[1] internal anchor tag placed at the insertion of the dorsal fin so that the tag locked between the posterior interneural rays and received a left pectoral fin clip to identify tag loss. Although one task was to estimate abundance of northern pike ≥300 mm FL, tagging fish ≥250 mm FL allowed for better assessment of gear selectivity for fish near 300 mm FL. To eliminate duplicate sampling in the second event, all fish received a lower caudal fin clip. All fish in both events were carefully inspected for attendant Floy™ tags and fin clips and had their capture/release locations recorded using a GPS (latitude and longitude coordinates as decimal degrees, NAD27 Alaska datum). Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and censored from the experiment.

[1] Product names used in this publication are included for completeness but do not constitute product endorsement.

Table 1.–Distribution of sampling effort for beach seining (S), gillnetting (G), and hook-and-line (H&L) during both events of the mark-recapture experiment in Volkmar Lake.

		Sampling section												
Event	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1														
	May 20	-	-	-	-	S[1]	-	-	-	-	-	-	S	S
	May 21	S	S	S	S	H&L	S[1]	S	S,H&L	G, H&L	-	S	S	S
	May 22	S	S	S	S	S	S	S	S	-	S	S	S	S[1]
	May 23	S	S[1]	S	S	S,G,H&L	S	S	S	-	S, H&L	S	S	S
	May 24	S	S	S	S	S,H&L	S	S	S[1],H&L	-	S	S	S	S
2														
	May 28	S	S	S	S[1]	S,H&L	S	S	S,H&L	H&L	S	S	S	S
	May 29	S[1],H&L	S,H&L	S,H&L	S,H&L	S	-	S	-	H&L	-	H&L	S,H&L	S,H&L
	May 30	SH&L	S,H&L	S,H&L	S,H&L	S,H&L	H&L	S,H&L	S[1],H&L	H&L	S,H&L	S,H&L	S,H&L	S,H&L
	May 31	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L	H&L

Note: S[1] – Represents the section where the first seine haul on a given day will occurred.

Table 2.–Catches of northern pike (all sizes) by gear, event, date, and section in Volkmar Lake during 2009. Dashes represent no effort.

Gear	Event	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL
Seine	1st	20-May	-	-	-	-	11	-	-	-	-	-	-	6	8	25
		21-May	10	3	35	9	-	7	7	1	-	-	8	60	16	156
		22-May	0	0	24	9	19	9	62	27	-	9	8	25	16	208
		23-May	3	28	21	3	19	6	31	4	-	0	4	4	86	209
		24-May	38	8	21	20	7	1	7	3	-	4	3	21	18	151
		subtotal	51	39	101	41	56	23	107	35	0	13	23	116	144	749
	2nd	28-May	10	13	33	11	9	2	7	2	-	5	8	5	14	119
		29-May	2	11	9	4	7	-	1	-	-	-	-	8	1	43
		30-May	2	6	14	9	0	-	2	4	-	2	4	3	0	46
		31-May	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		subtotal	14	30	56	24	16	2	10	6	0	7	12	16	15	208
	Total		65	69	157	65	72	25	117	41	0	20	35	132	159	957
H&L		20-May	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		21-May	-	-	-	-	0	-	-	4	10	-	-	-	-	14
		22-May	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		23-May	-	-	-	-	18	-	-	-	-	13	-	-	-	31
		24-May	-	-	-	-	28	-	-	31	-	-	-	-	-	59
		subtotal	0	0	0	0	46	0	0	35	10	13	0	0	0	104
		28-May	-	-	-	-	44	-	-	45	52	-	-	-	-	141
		29-May	6	14	10	9	-	-	-	-	29	-	4	15	37	124
		30-May	0	17	29	16	0	6	12	0	10	4	2	0	5	101
		31-May	10	26	5	7	8	10	40	16	15	1	0	6	5	149
		subtotal	16	57	44	32	52	16	52	61	106	5	6	21	47	515
	Total		16	57	44	32	98	16	52	96	116	18	6	21	47	619

DATA ANALYSIS

Abundance Estimate

Violations of Assumption 2 relative to size effects were tested using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size was required, capture probabilities by location were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A2) were used to determine if, for each identified length stratum, stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled Chapman-modified Petersen estimator, the completely stratified Chapman-modified Petersen estimator, or a partially stratified estimator (Darroch 1961). Testing was performed at the scale of a section.

Length and Age Compositions

Length and age compositions of the population were estimated using the procedures outlined in Appendix A3. Length composition was estimated in 25-mm length categories.

RESULTS

Abundance Estimate

A total of 1,579 northern pike were sampled over nine days. Of these, 957 were captured by the beach seine, 619 by hook-and-line, and three by gillnet (Table 2). Twenty fish <300 mm FL were captured and the smallest recaptured fish was 277 mm FL. For fish 300-449 mm FL, 199 were sampled (n_1=80, n_2=119, m_2=9), and for fish ≥450 mm FL 1,380 were sampled (n_1=776, n_2=604, m_2=116). No observed tag loss or immediate mortalities were observed during the experiment.

K-S tests (Appendix A1) results indicated length stratification was not required (Case III) for northern pike:

1) ≥300 mm FL;

    a) test M vs. R, D=0.06, P-value = 0.75;

    b) test C vs. R, D=0.17, P-value <0.01;

2) ≥450 mm FL;

    a) test M vs. R, D=0.07, P-value=0.63; and,

    b) test C vs. R, D=0.15, P-value=0.02 (Figure 3).

Consistency tests indicated that geographic stratification was not needed:

1) for fish ≥300 mm FL;

   a) mixing among sections was not complete (χ^2 = 206.5, P-value = 0.042; Table 3);

   b) probabilities of capture by section in the first event were not significantly different (χ^2 = 206.5, P-value = 0.08);

   c) probabilities of capture by section in the second event were not significantly different (χ^2 = 10.97, P-value = 0.61);

2) for fish ≥450 mm FL

   a) mixing was not complete (χ^2 = 186.6, P-value = 0.046; Table 4);

   b) probability of capture in the first event were not significantly different (χ^2 = 20.2, P-value = 0.06); and,

   c) probability of capture in the first event were not significantly different ((χ^2 = 9.57, P-value = 0.73).

Therefore the Bailey-modified Petersen estimator was used to calculate abundance estimate. Of interest was the estimated abundance of fish between 300-449 mm FL; however, there was insufficient data available for rigorous diagnostic testing and it was assumed that their attendant test results and conclusions were similar to that of fish ≥300 mm FL. The estimated abundance of northern pike in Volkmar Lake for fish:

1) ≥300 mm FL was 4,832 (95% C.I. = 4,124-5,539);

2) ≥300-499 mm FL was 971 (95% C.I. = 456-1,486); and,

3) ≥450 mm FL was 4,017 (95% C.I. = 3,417-4,614).

Length Composition

For all fish sampled, the most frequent 25-mm length categories ranged between 550 and 674 mm FL (Figure 4). For the estimated population of fish ≥450 mm FL, the most frequent length categories ranged between 600 and 675 (Appendix B1).

K-S tests indicated that the length composition of all fish captured by seining in both events combined differed from all fish captured by hook-and-line during the both events (D=0.12, P-value <0.01, Figure 4). The length composition of seine-caught fish in the first event differed from those in the second event (D = 0.29, P-value <0.01), and the length composition of fish caught in the first event using hook-and-line were not significantly different from those caught in the second event (0.09, P-value = 0.49).

Table 3.–Number of northern Pike ≥300 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in Volkmar Lake, 2009.

	Section recaptured															
Section Marked	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**m_2**	**n_1**	**m_2/n_1[b]**
1	1	1	3	0	0	1	0	1	0	0	0	0	0	7	51	0.14
2	0	0	2	0	0	0	0	0	0	0	0	0	0	2	38	0.05
3	1	2	13	0	0	1	0	3	0	0	0	0	0	20	101	0.20
4	0	0	0	3	0	0	1	1	1	0	0	1	0	7	41	0.17
5	0	0	2	3	1	2	3	5	1	0	0	0	0	17	102	0.17
6	0	0	0	1	0	0	0	1	0	0	0	0	0	2	23	0.09
7	1	0	2	2	2	0	2	0	5	1	0	0	4	19	107	0.18
8	0	1	0	1	1	0	1	3	1	0	0	0	2	10	70	0.14
9	1	0	0	0	0	0	0	0	2	0	0	0	0	3	12	0.25
10	0	0	0	0	1	0	1	1	0	0	0	0	1	4	26	0.15
11	0	0	1	0	1	0	0	0	1	0	1	0	0	4	23	0.17
12	1	2	1	0	0	0	0	1	4	0	0	2	0	11	116	0.09
13	1	1	2	3	1	0	0	0	4	0	2	1	3	18	141	0.13
m_2	6	7	26	13	7	4	8	16	19	1	3	4	10	124	851	0.15
n_2	30	86	99	53	65	18	61	65	106	9	17	37	62	708		
(m_2/n_2)[a]	0.20	0.08	0.26	0.25	0.11	0.22	0.13	0.25	0.18	0.11	0.18	0.11	0.16	0.18		

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Table 4.–Number of northern Pike ≥450 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in Volkmar Lake, 2009.

	Section recaptured															
Section Marked	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**m_2**	**n_1**	**m_2/n_1**[b]
1	1	0	3	0	0	1	0	1	0	0	0	0	0	6	45	0.13
2	0	0	2	0	0	0	0	0	0	0	0	0	0	2	24	0.08
3	1	2	12	0	0	1	0	3	0	0	0	0	0	19	97	0.20
4	0	0	0	3	0	0	1	1	1	0	0	1	0	7	35	0.20
5	0	0	2	3	1	2	3	4	1	0	0	0	0	16	93	0.17
6	0	0	0	1	0	0	0	1	0	0	0	0	0	2	22	0.09
7	1	0	2	2	2	0	2	0	5	1	0	0	4	19	105	0.18
8	0	1	0	1	1	0	1	2	1	0	0	0	2	9	59	0.15
9	1	0	0	0	0	0	0	0	0	0	0	0	0	1	10	0.10
10	0	0	0	0	1	0	1	1	0	0	0	0	1	4	20	0.20
11	0	0	1	0	1	0	0	0	1	0	1	0	0	4	23	0.17
12	1	2	1	0	0	0	0	1	4	0	0	1	0	10	115	0.09
13	1	1	2	3	1	0	0	0	3	0	2	1	3	17	128	0.13
m_2	6	6	25	13	7	4	8	14	16	1	3	3	10	116	776	0.15
n_2	25	71	87	43	49	18	59	56	81	6	15	35	59	604		
(m_2/n_2)[a]	0.24	0.08	0.29	0.30	0.14	0.22	0.14	0.25	0.20	0.17	0.20	0.09	0.17	0.19		

[a] Probability of capture during first event.

[b] Probability of capture during second event.

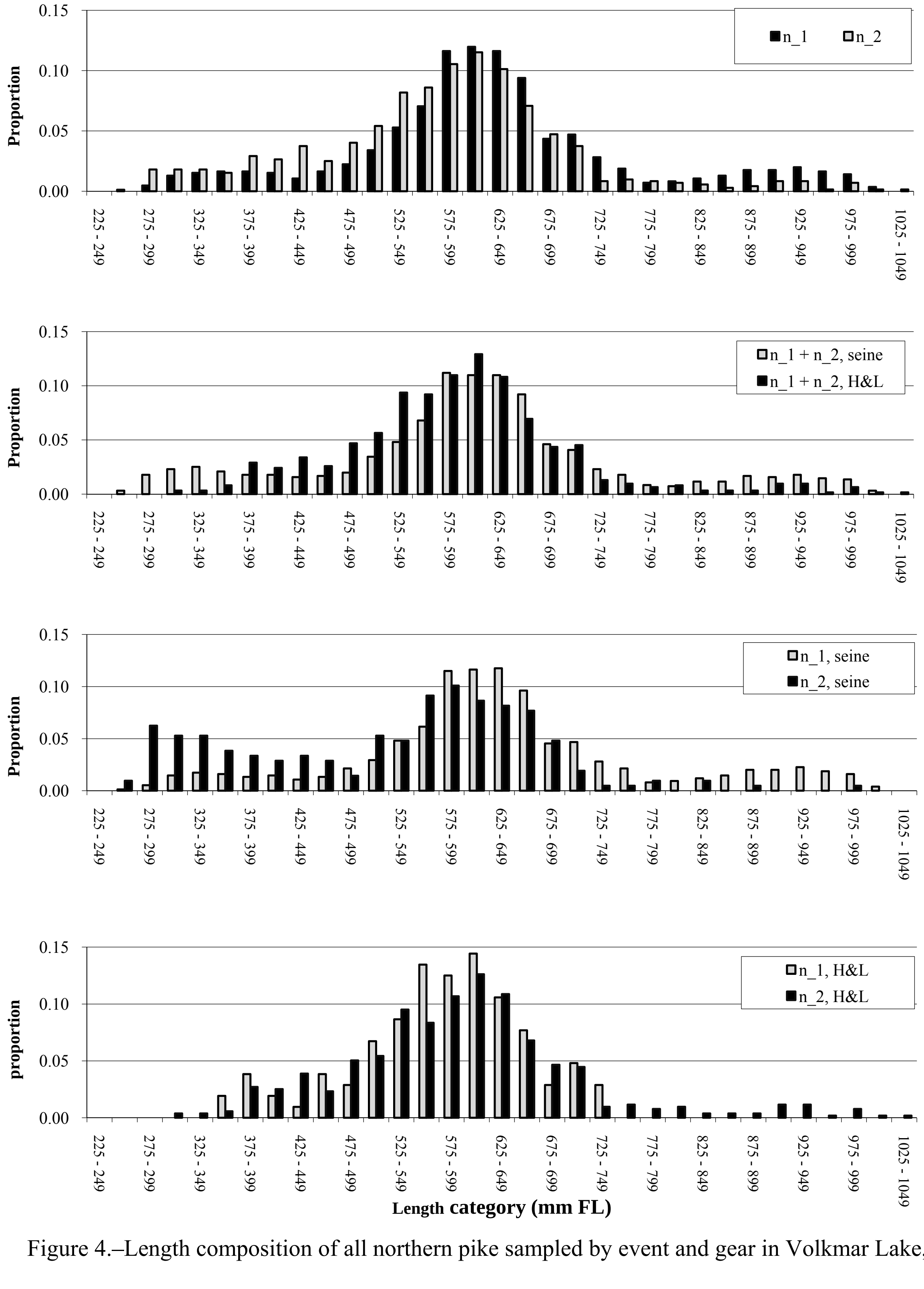

Figure 4.–Length composition of all northern pike sampled by event and gear in Volkmar Lake, 2009.

DISCUSSION

The study design in 2009 resulted in greater precision and more rigorous diagnostic testing than during the most recent experiments conducted in 1992–1994, 2000 and 2005, which used a multi-event design and the program capture (Rexstad and Burnham 1992). The multi-event experiments were conducted by beach seining all 13 sections in a given day over an 8- to 10-day period and relied on the assumption that a representative sample of the population was attained in a given day or event. However, beach seining is problematic because its effectiveness varies with shoreline gradients. Catchability tends to be greater along shallow-sloped shoreline than steeper sloped areas, where it can be difficult to capture even one fish. Therefore satisfying the assumptions of the multi-event model can become dubious.

For example, in 2005, the multi-event design was implemented during sampling, but after preliminary data analysis, the data were restructured as a two-event experiment because the assumptions of the multi-event experiment could not be satisfied (Wuttig and Reed *in prep*). An additional problem in 2005 was the absence of any recaptured fish for a number of sampling sections which made it difficult to detect and correct for any biases. In four sections, none the fish marked were recaptured among all sections, and no fish from other areas were recaptured in any of these four sections.

To investigate the potential drawbacks of the multi-event design further, the data set from 2000 was restructured as a two-event experiment (4-days each event). In this case, the abundance estimate for fish ≥300 mm FL was 1,686 fish ≥300 mm FL, compared to 1,491 fish for the multi-event. However, this estimate is questionable because in more than half of the sections (8 of 13), none the fish marked in these eight sections were recaptured among all sections, and no fish from other areas were recaptured in any of these eight sections. Moreover, there was a strong indication that there was very little movement or mixing. Of the eight recaptured fish, only one fish moved (to an adjacent section), and four of the eight fish were marked and recaptured in the same section (section 7), which is an easily seined section. The lack of movement indicates that the 2000 estimate may be biased low because a potentially large portion of the population was isolated from the experiment (i.e. those in the center of the lake or in areas not easily seined).

The 2009 study design is recommended for future sampling efforts because it resulted in good precision, a representative sample was attained, and the high number of recaptures from all sections resulted in fairly rigorous diagnostic testing. During the hiatus, complete mixing was almost achieved and effectiveness hook-and-line was higher than anticipated. Sufficient numbers of pike caught using hook-and-line gear in the steep-sloped sections and offshore areas helped to alleviate concerns over any fish being isolated from the experiment. Although, hook-and-line captured larger fish than the seine (Figures 4 and 5), hook-and-line sampling did surprisingly capture a more representative length distribution than did beach seining. Diagnostic tests indicated a representative sample of the population was attained in the second event, where a majority of the fish were captured using hook-and-line (72%), but not in the first event when most (88%) were captured with the seine. Lastly, it should be noted that hook-and-line worked particularly well in areas where the lake bottom transitioned from a shallow shelf to deep waters (e.g., from ~10 to ≥30 ft).

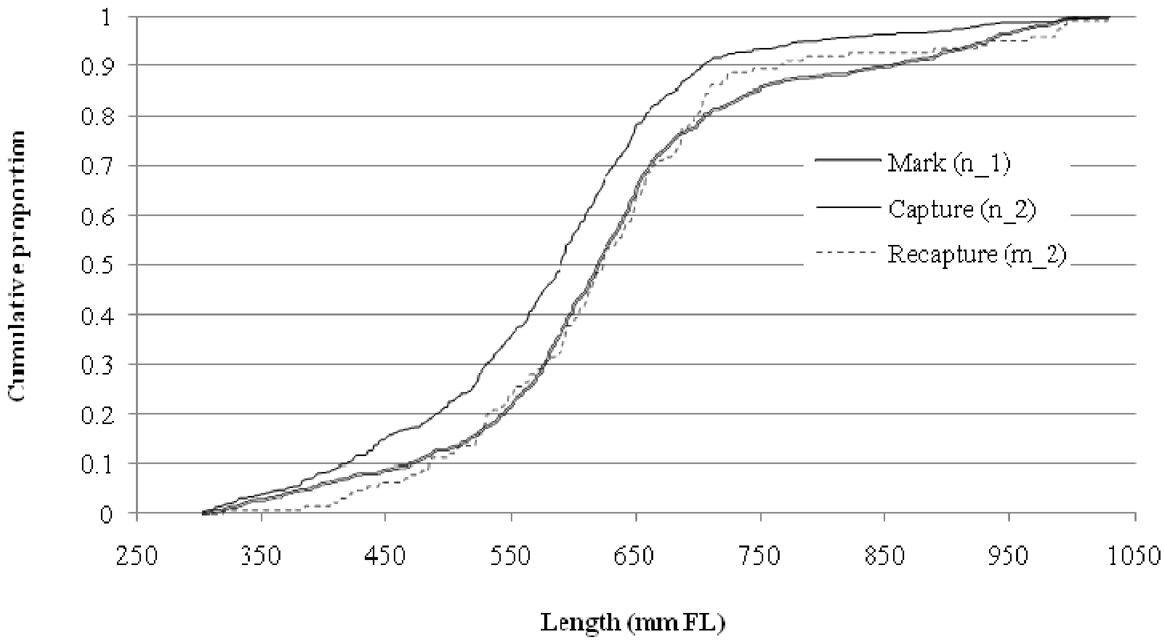

Figure 5.–Cumulative proportion of fish ≥300 mm FL sampled during the first and second events and the recaptures during the second event in Volkmar Lake, 2009.

Some potentially interesting behavior was observed in 2009 as it related to the timing of the experiment and should be considered in the design of future sampling efforts. The experiment was to start immediately after ice-out when fish are still spawning along the shorelines and more easily seined. Though shorelines were ice free in 2009, a lack of wind delayed the break-up of a large pan of ice covering most of the lake. When sampling finally started, spawning was nearly complete because only handful of fish could be reliably sexed (i.e. extrusion of sex products). An antidotal pattern has been observed in lakes of Interior Alaska over the years where the larger, mature fish move offshore and become more absent near shore as the waters warm and spawning ceases. In 2009, this generalized trend may explain why higher proportions of smaller fish were sampled with the beach seine in the second event (Figure 4).

The length composition of fish sampled in 2000, 2005 and 2009 was examined for population trends during what was functionally a period of no fishing mortality (i.e. annual harvests averaged 37 fish). Visually, the data proved very interesting because it clearly shows distinct modes or “cohorts” moving through the population (Figure 6). Although the 2000 estimate was potentially biased low, it was still sufficiently accurate in depicting that abundance was relatively low and composed primarily of smaller fish (i.e. 300-450 mm FL), and only a handful of larger fish (e.g. ≥700 mm FL). In 2005, this cohort of smaller fish can be seen recruiting to the larger sizes, with another smaller cohort appearing as well. By 2009, the population abundance had increased markedly, a cohort of smaller sized fish was absent, and the population dominated by “medium” sized fish. Although it is merely conjecture, the changes in the populations abundance and length composition may be a prelude to a significant population “crash”, similar to what was observed in 2000. With such a large population of effective cannibalistic predators competing for juvenile pike and whitefish, recruitment may be difficult as this very strong cohort naturally progresses toward their maximum ages. A population assessment in four to six years should be interesting.

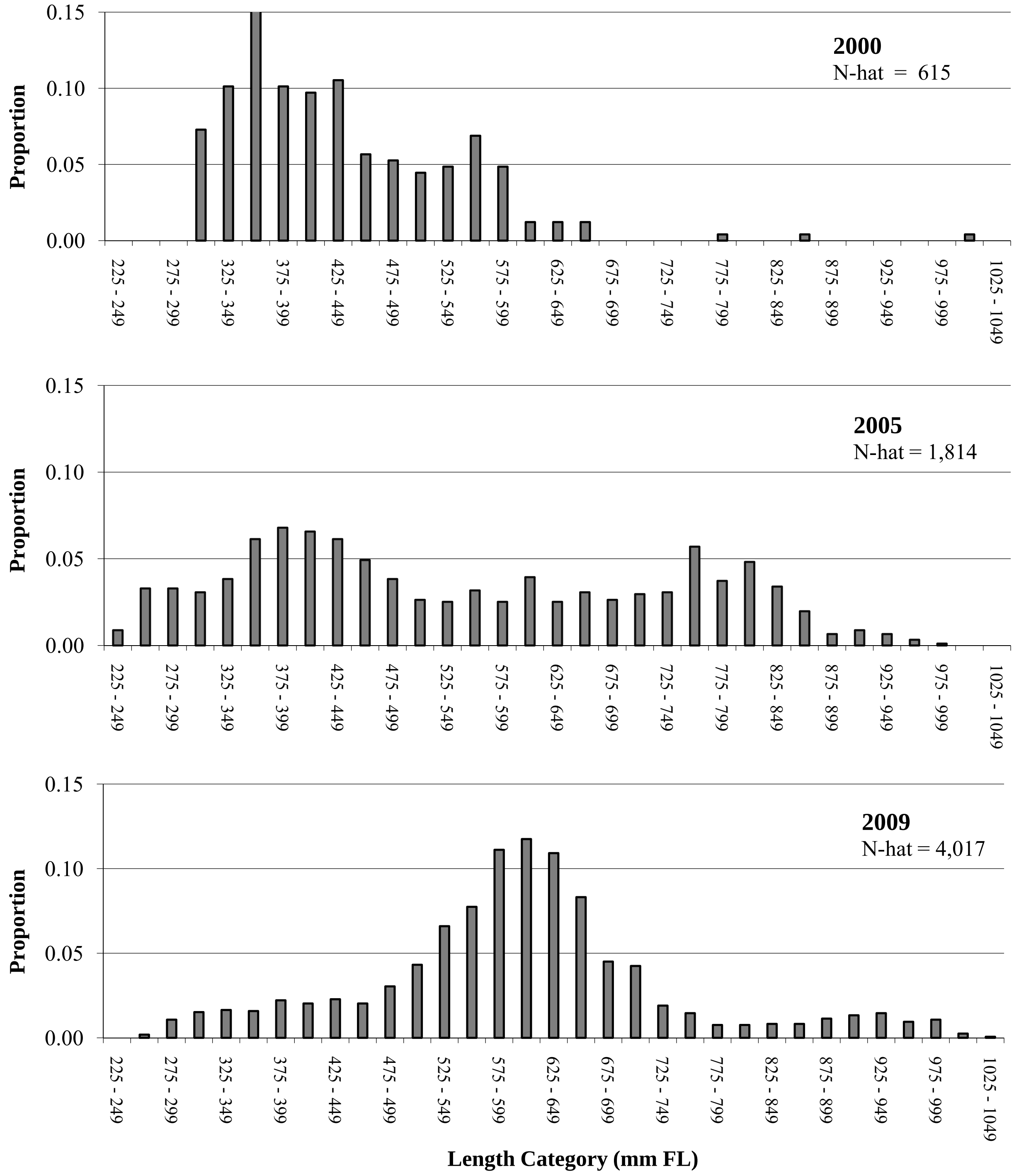

Figure 6.–Length composition of all northern pike sampled at Volkmar Lake and estimated abundance of fish ≥450 mm FL during the three most recent assessments, 2000, 2005, and 2009.

The information collected in this study provided for unambiguous interpretation of the interim management objective. In Volkmar Lake, the estimated population size of northern pike ≥450 mm FL far exceeded the defined threshold of 2,000 fish. Based on these results the Department supported a proposal to increase the bag limit of northern pike in Volkmar Lake. In 2010, the Alaska Board of Fisheries increased the bag limit from one fish to two fish. Recent harvest trends indicate that a two fish bag limit will be sustainable.

It is recommended that future management take into account that natural variation, not fishing mortality, has been the overriding factor for the observed shifts in abundance and length composition, which is particularly apparent since 2000 (Figure 6). An interim management objective of (i.e. ≥2,000 northern pike ≥450 mm FL) has been used as a decision criterion for allowing greater harvest, but fails to address criteria needed to restrict the fishery. The observed "recovery" of the population from 2000 to 2009 strongly suggests that even if relatively small population sizes (i.e. 500 fish ≥450 mm FL) are observed in the future, more restrictive regulations (e.g. a bag limit of one fish or seasonal closures) are not warranted. Applying more restrictive regulations would likely result in missed opportunities for harvesting the surplus northern pike recruited to the population, as in hindsight, had occurred from 2000–2009.

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APPENDIX A

Appendix A1.–Detection of size and/or sex selective sampling during a two-sample mark recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's t-test).

M vs. R C vs. R M vs. C

Case I:

Fail to reject H_o Fail to reject H_o Fail to reject H_o

There is no size/sex selectivity detected during either sampling event.

Case II:

Reject H_o Fail to reject H_o Reject H_o

There is no size/sex selectivity detected during the first event but there is during the second event sampling.

Case III:

Fail to reject H_o Reject H_o Reject H_o

There is no size/sex selectivity detected during the second event but there is during the first event sampling.

Case IV:

Reject H_o Reject H_o Either result possible

There is size/sex selectivity detected during both the first and second sampling events.

Evaluation Required:

Fail to reject H_o Fail to reject H_o Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

-continued-

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.
Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.
Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.
Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and,} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k\right)^2 \hat{V}[\hat{N}_i] \right). \tag{2}$$

where: j = the number of sex/size strata;
$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;
$\hat{N}_i$ = the estimated abundance in stratum *i*; and,
$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing[a]

Section Where Marked	Section Where Recaptured				Not Recaptured
	A	**B**	**…**	**F**	(n_1-m_2)
A					
B					
...					
F					

II.-Test for equal probability of capture during the first event[b]

	Section Where Examined			
	A	**B**	**…**	**F**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during the second event[c]

	Section Where Marked			
	A	**B**	**…**	**F**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from section i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among sections: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among sections: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A3.–Equations for calculating estimates of abundance and its variance using the Chapman-modified Petersen estimator.

The abundance of northern pike was estimated as:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{(m_2 + 1)} - 1, \tag{A3-1}$$

where:

n_1 = the number of northern pike released alive during the first event;

n_2 = the number of northern pike examined for marks during the second event; and,

m_2 = the number of northern pike marked in the first event that were recaptured during the second event.

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}. \tag{A3-2}$$

Appendix A4.–Equations for estimating length composition and variances for the population.

From Appendix B1, Case III was determined through inference testing and occurs when there is size selectivity during the first event, but not for the second event. Proportions from the second event in 25-mm FL categories were calculated by:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \qquad \text{(A4-1)}$$

where:

n_j = the number sampled from size stratum *j* in the mark-recapture experiment;

n_{jk} =the number sampled from size stratum *j* that were in length category *k*; and,

$\hat{p}_{jk}$ = the estimated proportion of length category *k* in size stratum *j*.

The variance of this proportion was estimated as (from Cochran 1977):

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1 - \hat{p}_{jk}\right)}{n_j - 1}. \qquad \text{(A4-2)}$$

APPENDIX B

Appendix B1.–Estimated length composition of northern pike in Volkmar Lake, 2009.

	≥300 mm FL		≥450 mm FL	
Length Category	P	SE	P	SE
300–324	0.018	0.005		
325–349	0.018	0.005		
350–374	0.015	0.005		
375–399	0.029	0.006		
400–424	0.026	0.006		
425–449	0.037	0.007		
450–474	0.025	0.006	0.043	0.008
475–499	0.040	0.007	0.029	0.007
500–524	0.054	0.008	0.046	0.008
525–549	0.082	0.010	0.062	0.010
550–574	0.086	0.010	0.094	0.012
575–599	0.105	0.011	0.098	0.012
600–624	0.115	0.012	0.121	0.013
625–649	0.101	0.011	0.132	0.013
650–674	0.071	0.010	0.116	0.013
675–699	0.047	0.008	0.081	0.011
700–724	0.037	0.007	0.054	0.009
725–749	0.008	0.003	0.043	0.008
750–774	0.010	0.004	0.010	0.004
775–799	0.008	0.003	0.011	0.004
800–824	0.007	0.003	0.010	0.004
825–849	0.006	0.003	0.008	0.004
850–874	0.003	0.002	0.006	0.003
875–899	0.004	0.002	0.003	0.002
900–924	0.008	0.003	0.005	0.003
925–949	0.008	0.003	0.010	0.004
950–974	0.001	0.001	0.010	0.004
975–999	0.007	0.003	0.002	0.002
1000–1024	0.001	0.001	0.008	0.004
1025–1049	0.001	0.001	0.002	0.002

APPENDIX C

Appendix C1.–Data files[a] for all northern pike sampled in the Volkmar Lakes, 2009.

Data file	Description
Volkmar Northern Pike data_Archive .xls	Data 2009 mark-recapture, seine, and H&L sampling; historic comparisons

[a] Data files are archived at and are available from the Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.